NATURALISTIC CYCLING STUDY: IDENTIFYING RISK FACTORS FOR ON-ROAD COMMUTER CYCLISTS

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ABSTRACT – The study aim was to identify risk factors for collisions/near-collisions involving on-road commuter cyclists and drivers. A naturalistic cycling study was conducted in Melbourne, Australia, with cyclists wearing helmet-mounted video cameras. Video recordings captured cyclists' perspective of the road and traffic behaviours including head checks, reactions and manoeuvres. The 100-car naturalistic driving study analysis technique was adapted for data analysis and events were classified by severity: collision, near-collision and incident. Participants were adult cyclists and each filmed 12 hours of commuter cycling trips over a 4-week period. In total, 127 hours and 38 minutes were analysed for 13 participants, 54 events were identified: 2 collisions, 6 near-collisions and 46 incidents. Prior to events, 88.9% of cyclists travelled in a safe/legal manner. Sideswipe was the most frequent event type (40.7%). Most events occurred at an intersection/intersection-related location (70.3%). The vehicle driver was judged at fault in the majority of events (87.0%) and no post-event driver reaction was observed (83.3%). Cross tabulations revealed significant associations between event severity and: cyclist reaction, cyclist post-event manoeuvre, pre-event driver behaviour, other vehicle involved, driver reaction, visual obstruction, cyclist head check (left), event type and vehicle location ($p<0.05$). Frequent head checks suggest cyclists had high situational awareness and their reactive behaviour to driver actions led to successful avoidance of collisions/near-collisions. Strategies to improve driver awareness of on-road cyclists and to indicate early before turning/changing lanes when sharing the roadway with cyclists are discussed. Findings will contribute to the development of effective countermeasures to reduce cyclist trauma.

INTRODUCTION

Cycling is the fourth most popular physical activity in Australia, behind walking, aerobic/fitness and swimming, and the number of people riding bicycles is increasing, up 11% from 2001 to 2007 (Department of Communications Information Technology and the Arts, 2008). All levels of Australian government have road safety strategies that incorporate cycling and some have cycling specific strategies (Austroads, 2005, VicRoads, 2008c, City of Melbourne, 2007). Cycling facilities that have benefited cyclist safety in the United Kingdom, Europe and the United States (McClintock and Cleary, 1996, Pucher et al., 2010) have been implemented in Australian jurisdictions (eg bicycle lanes and bicycle storage boxes/advanced stop lines) to create a delineated space for cyclists on the road.

Notwithstanding the rise in participation, nationally the number of cyclist fatalities has remained relatively constant with an average of 37 cyclist deaths per year from 1999 to 2008 (Department of Infrastructure, 2009). However, there has been a dramatic increase in the number of crashes resulting in cyclist serious injuries (Berry and Harrison, 2008, Sikic et al., 2009). As the number of cyclists on the road continues to increase, the potential for cyclist-driver collisions is a growing concern, particularly as these collisions result in the most severe injury outcomes and poorest survival rate for cyclists (Bostrom and Nilsson, 2001).

An Australian review of police and coronial reports for 222 cyclist fatalities found that in over 60% of collisions a major contributing factor was that cyclists and drivers did not see each other (Australian Transport Safety Bureau, 2006). Numerous studies have sought to investigate the looking behaviour of drivers: driver hazard perception (Benda and Hoyos, 1983), at intersections and the role of speed reducing countermeasures (Summala et al., 1996, Summala and Rasanen, 2000) and detecting approaching motorcyclists (Clarke et al., 2007). Investigations of visual scanning strategies have found many drivers looked-but-failed-to-see cyclists (Herslund and Jørgensen, 2003), and that drivers look to cyclists' faces to assess intended behaviour rather than their hand/arm (Walker, 2005, Walker and Brosnan, 2007). However, less attention has been given to understanding the *in situ* looking behaviour and situational awareness of cyclists pre-event in relation to collisions or near-collisions.

In the United Kingdom, helmet mounted cameras have been used in mobility research to investigate the experiences of mountain bike riders (Brown et al., 2008) and riding styles in London (Brown and Spinney, 2010). However, these studies focused on the development and critique of video ethnography as a method that could provide researchers with a virtual ride-along experience that had not been achieved via other methods. It is believed that to date, this method has not been used to investigate how cyclists and drivers interact on the road and the risk factors associated with collisions and near-collisions.

In addition, there are limitations in using post-event data to understand pre-crash factors and it is difficult to determine the looking behaviour of a cyclist prior to a fatality collision (Räsänen and Summala, 1998). The data is typically generated by statements from the driver involved or witness accounts, both subject to reporting biases and errors; or from crash scene investigations which are not able to provide details on all salient cyclist-related pre-event actions. In fatal crashes, clearly the deceased cyclist is unable to contribute, however, additional cyclist-related data may be generated if the cyclist was riding in a group. To better understand the role of cyclist looking behaviour and the contributing factors of other situational and behavioural factors it is important to understand what cyclists see when riding and their reactions to the traffic environment.

Looking behaviour of cyclists

Cyclist visual scanning research has found that head checks are an important indicator of intended behaviour. Räsänen and colleagues conducted video observations in a study of yield behaviour at intersections following a change in Finnish legislation regarding vehicle priority. An analysis of the head movements of 2,112 cyclists found an association between more frequent head movements with greater caution (Räsänen et al., 1999).

In a series of studies, Plumert and colleagues investigated the behaviour of cyclists using a range of traffic scenarios in a bicycle simulator (Plumert et al., 2004, Plumert and Kearney, 2007, Plumert et al., 2007). The research focused on the cognitive and perceptual skills of children and behaviour at intersections, particularly gap selection differences between children and adults. The focus on child riders provided useful insights into children's cycling behaviour and decision making processes; however these studies included little detail of adult cyclists' looking patterns. Moreover, many questions remain about adult cyclists, their behaviour when interacting with drivers, how drivers interact with cyclists and the on-road space afforded to riders.

Systems approach

Beyond cyclist-driver behaviours, it is important to consider how the road network and the environment may potentially contribute to crash and injury risk. To focus solely on the behaviour of cyclists and drivers assumes that the road network system is perfect and it is only due to errors by the road users a crash occurs (Larsson et al., 2010). The road user approach lacks an understanding of the importance of interactions between all components of the traffic system and emergent issues.

The actions of cyclists and drivers on the road are facilitated and shaped by the design of the road (Elvebakk and Steiro, 2009). There has been little attention given to the safety implications of the on-road cycling facilities and how cyclists and drivers negotiate the available space on the road. This is of particular importance in Australia, where to date a range of on-road cyclist facilities, primarily painted lines, have been implemented. However, there have not been broad public communication/education campaigns for drivers that explain the facilities or to help drivers understand how to interact with the increasing number of cyclists on the roads.

The aim of this study was to investigate the pre-event behaviours and environment to identify risk factors for collisions and near-collisions involving on-road cyclists and drivers. Given the increasing number of cyclists in Australia, and the lack of research focus on the safety implications of the pre-event risk factors, it is anticipated that the findings will contribute substantially to the knowledge of factors that affect cyclists' safety and highlight recommendations that may reduce cyclist trauma.

METHODS

Research design

This was a naturalistic study of on-road commuter cyclists. A video camera was attached to participants' bicycle helmet, each participant recorded 12 hours of their commuter cycling trip over a 4-week period. The study was conducted during warmer months from October to December 2009, commencing with the start of daylight savings (summer time).

Helmet mounted video camera

The compact video cameras used (Oregon Scientific ATC3K Action Camera) were powered by two AA batteries and weighed approximately 240gm with the memory card and batteries installed. Footage was recorded at 640 x 480 VGA resolution at 30 frames per second. Participants were provided with 6 memory cards (4GB) and sufficient batteries. A display screen indicated recording time remaining on the memory card and participants changed the cards and batteries as required. The data was downloaded by the researcher at the end of the study.

Extensive pilot testing was conducted to determine the most suitable camera position including on the handlebars and under the seat. The handlebar mount was discounted as it did not capture cyclists' head movements or the broader environment which are important in the event of a collision or near-collision (Walker, 2007). Further, there were potential space limitations on the handlebars due to other equipment that may already be attached eg trip computer or lights. The under-seat mount clearly recorded the vehicular traffic behind the rider and would capture rear-end events. This perspective was of interest as rear-end collisions result in the highest proportion of cyclist fatalities in Australia (21%) (Australian Transport Safety Bureau, 2006). However, despite risk of fatal outcome, rear-end collisions are rare and this mounting was discarded in preference of a forward-facing camera position.

In the study induction, the camera was attached to the helmet and each participant rode a short test ride. Test footage was reviewed and the camera position was adjusted if necessary. The camera was secured with adhesive putty and an exterior grade reinforced tape and remained attached for the study duration. Camera position varied depending on bicycle type, helmet design and participant's position on the bicycle.

Participant recruitment

The participant inclusion criteria were: over 18 years, regularly cycle commuted to and from work, travelled the majority of trip (70%) on-road and able to film 12 hours of footage over a 4-week period. All non-electric bicycle types were accepted, excluding recumbent bicycles.

A quota sample of participants was sought to include footage from a range of approach routes into the Melbourne central business district (CBD). The installation of cycling facilities and traffic calming measures is not uniform across the city. Initially, participants were recruited using a snowball technique however this process failed to yield participants who used the most frequently used on-road commuter route into the CBD (along St Kilda Road). Targeted recruitment via an article in the local newspaper was used to recruit commuters in the area.

Data collected

Footage

The recording time of 12 hours was calculated using the average distance ridden by commuter cyclists, which in Victoria is 24.3km (return trip). During the warmer months of October to March, over 50% of cyclists rode 3-5 days per week (Bicycle Victoria, 2007). The assumptions were that participants would ride the average distance, a minimum of 3 times per week and ride at least at the average speed of a healthy, untrained adult (20km/h)(de Geus et al., 2007).

It was also assumed that 12 hours of trips would provide a range of experiences representative of typical trips and also give participants the opportunity to 'forget' their behaviour was being filmed. Drivers in the 100-car study were found to be cautious at the beginning of the study, however, this effect wore off after the first hour (Dingus et al., 2006).

Other data

In addition, participants completed a survey about their driving/cycling experiences, provided weekly updates and completed an exit interview about their study experience, cycling safety and general topics including helmets, headphones and registration. These data are not considered in this paper.

Data analysis

Data analysis was conducted in four stages: an initial footage review; identification of events, classification of event characteristics and; statistical analysis. Excluded was footage recorded when participants rode off-road including bike paths and footpaths and; footage recorded during low light hours as the camera had poor light sensitivity.

The footage was reviewed using InterVideo WinDVD 5 viewing software. Aggregated descriptive statistics and cross-tabulations were calculated using PASW Statistics 18.

Definitions

The definitions used were adapted from the first comprehensive naturalistic driving study (Neale et al., 2002). The study was the 100-car study conducted by researchers at the Virginia Technology Transport

Institute in the United States of America and used using five cameras in each of the 100 vehicles. The footage recorded for the first time typically unreported minor events and insights into pre-collision behaviours.

The 100-car study included five levels of event severity, however the level of detail required to use these definitions was not recorded by a single camera. Three event severities were identified: collision, near-collision and incident. A *collision* involved contact between the cyclist and another road user with kinetic energy transference. A *near-collision* required rapid, evasive manoeuvring from the cyclist and/or the driver to avoid a collision, eg sudden braking or swerving. An *incident* required some collision avoidance, but was less sudden than the near-collision event and included close vehicle proximity which results when drivers did not allow sufficient space when overtaking cyclists.

Event characteristics were classified using modified variables from the 100-car study data dictionary and incident types were classified using codes from the VicRoads Definitions for Classifying Accidents (DCA)(VicRoads, 2008a). The 100-car study data dictionary classified 44 incident characteristics which comprehensively define elements of the event from a driver/vehicle perspective. Some modification was needed to adapt the variables to the cyclist footage.

In total, 20 variables were adopted from the 100-car study without change, including pre-incident behaviour, the road and traffic environment and the behaviour of the secondary vehicle involved. Included was the variable *fault*, defined as cyclist/driver who committed an error and was only coded if there was observable evidence.

A further eight variables were modified, mainly changing the referent from driver to cyclist and adapting the references to the Australian driving context (left lane drive). The *pre-incident manoeuvre judgement* variable included *safe and legal*. This was defined in the 100-car study based on vehicle kinematics. The definition was modified to describe the positioning of the participant, both on the road and in relation to vehicular traffic. For example, riding straight, in an on-road bicycle lane would be coded as *safe and legal*. In addition, the variable related to direction and speed of travel (*going straight, constant speed*) was modified to include direction only (*going straight*) as cyclists' speed was not recorded.

In total, 16 variables were excluded, mainly related to driver behaviour recorded by the internal cameras used in the 100-car study. Additional cycling specific variables were developed and included cyclist head checks, cycling facility presence/type at the event site and use of vehicle indicators prior to lane changes.

In observational studies there is potential for coding bias, particularly when only one researcher codes all the data. To address this, an independent researcher recoded two variables (*event severity* and *event nature*) for 6 of the 54 events (11.1%). The results were analysed using the Kappa statistic. The inter-rater reliability were *event severity*, Kappa = 0.667 and *event nature* Kappa = 0.769. Both measurements can be interpreted as being of substantial agreement (Landis and Koch, 1977).

RESULTS

Footage

The total time recorded by all participants was 138 hours 51 minutes. In total, 11 hours and 13 minutes of footage was excluded due to riding off-road or low light. After exclusions, the total video footage available for analysis was 127 hours 38 minutes. Summary statistics for the video recordings are presented in Table 1.

Table 1 - Descriptive statistics of the recorded footage (AM & PM)

	Females (n=2)	Males (n=11)	Total
Time recorded	21:18	117:33	138:51
Excluded time			
- Low light	0:25	1:39	2:04
- Off road	2:25	6:44	9:09
Total time analysed	18:28	109:10	127:38

Events

In total, 54 events were identified: 2 collisions, 6 near-collisions and 46 incidents. The descriptive statistics for selected variables are cross tabulated with event severity and presented in Table 2.

Most cyclists were observed to be riding in a safe and legal manner pre-event (87.0%). Prior to the events, cyclists were observed making right head checks (57.3%) but fewer left head checks (37.1%). With the exception of the 2 collisions, all cyclists maintained control of their bicycle and most avoided a collision by braking (75.9%).

Table 2 – Summary data for key variables for each event severity type (n=54 events)

		Event severity				
		Collision	Near collision	Incident	Total	(category %)
Number of events		2	6	46	54	(100%)
Time	AM	2	5	23	30	(55.6%)
	PM	-	1	23	24	(44.4%)
Traffic control	no traffic control	2	4	41	47	(87.0%)
	traffic signal	-	2	3	5	(9.2%)
Relation to junction	non-junction	1	2	12	15	(27.7%)
	intersection/ intersection-related	1	4	33	38	(70.3%)
Bike lane	yes	1	2	21	24	(44.4%)
	no	1	4	25	30	(55.6%)
DCA code	110 Cross traffic	2	-	-	2	(3.7%)
	116 Merging from left	-	-	9	9	(16.6%)
	135 Sideswipe	-	3	19	22	(40.7%)
	137 Left turn across	-	1	8	9	(16.6%)
	163 Vehicle door	-	-	2	2	(3.7%)
Fault	driver	1	4	42	47	(87.0%)
	cyclist	1	1	3	5	(9.2%)
	unknown	-	1	1	2	(3.7%)
Cyclist pre-event behaviour	safe and legal	1	4	42	47	(87.0%)
	unsafe and illegal	-	-	2	2	(3.7%)
	safe but illegal	-	-	1	1	(1.8%)
	unsafe and legal	1	2	1	4	(7.4%)
Cyclist head check – left	no	1	3	30	34	(62.9%)
	1-5 times	1	2	2	5	(9.2%)
	5+ times	-	1	14	15	(27.7%)
Cyclist head check – right	no	2	3	18	23	(42.5%)
	1-5 times	-	1	12	13	(24.0%)
	5+ times	-	2	16	18	(33.3%)
Cyclist reaction	steered to the left	-	1	3	4	(7.4%)
	braked	1	2	13	16	(29.6%)
	slowed (shook head)	-	1	24	25	(46.2%)
	no reaction	-	-	6	6	(11.1%)
Cyclist post-event	maintained control	-	6	46	52	(96.2%)
	did not maintain control	2	-	-	2	(3.7%)
Vehicle type	car	1	2	30	33	(61.1%)
	4WD/SUV	1	1	5	7	(12.9%)
	large/commercial vehicle	-	3	8	11	(20.3%)
	motorcycle	-	-	2	2	(3.7%)
Driver pre-event behaviour	illegal passing	-	-	3	3	(5.5%)
	did not see cyclist	2	5	10	17	(31.4%)
	turned/merged too close in front of cyclist	-	-	30	30	(55.5%)
Vehicle indicated	yes	-	2	22	24	(44.4%)
	no	-	4	14	18	(33.3%)
	N/A, unknown	2	-	10	12	(22.2%)
Driver reaction	no reaction	-	4	41	45	(83.3%)
	braked	2	2	5	9	(16.6%)

The most frequent event type observed was sideswipes (40.7%). When grouped together with other actions that involved the vehicle in the adjacent lane turning or merging left across the path of the cyclist, this type of action resulted in 72.2% of all events observed (example see Figure 1). The two collisions observed involved cross traffic.

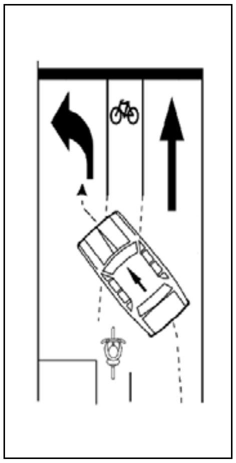

Figure 1 Left turn across cyclist path

Drivers were determined to be at fault in the majority of events (87.0%). In these driver-at-fault events, the most frequent event type was driver left manoeuvres including turning left and turning left across the path of the cyclist (55.5%). This was the most frequent pre-event driver behaviour across all vehicle types, with the exception of 4WD drivers who were more likely to not see the cyclist (85.7%). Post-event there was no identifiable reaction from the driver, such as braking or slowing (83.3%).

The vehicle indicator status was known for most events (77.8%), unknown for 11.1% and not applicable for 11.1% of the events. When the vehicle's indicator could be observed, 57% of drivers did indicate (or signal) before they changed course. However, of the drivers who did indicate, half (50.0%) indicated for only 1-3 seconds before changing course.

A similar number of events occurred during the morning (55.6%) and afternoon (44.4%) trips. The majority of events occurred at intersections or at intersection-related sites (70.3%); however the majority of these sites did not have any form of traffic control (including traffic lights or signage) (87.5%). There was no designated bike lane at over half the sites where an event occurred (55.5%).

Each variable was cross tabulated with event severity and Fisher's Exact Test, a test to determine the significance of associations between categorical data, was used. Significant associations ($p<0.05$) were found between event severity and pre-event factors: pre-event driver behaviour (turned/merged too close in front of cyclist), cyclist reaction (braked), cyclist head check (left); event type (sideswipe); and post-event factors, cyclist post-event manoeuvre (maintained control) and driver reaction (no reaction).

DISCUSSION

All identified collisions, near-collisions and incidents were analysed in-depth to identify the risk factors for cyclists. Overall, on-road commuter cyclists rode in a safe and legal manner and used cycling facilities when available. In addition, cyclists rode in a manner that was anticipatory (avoiding potential collisions) and defensive or reactive to the surrounding vehicular traffic as drivers did not appear to see them.

Cyclists made frequent head checks throughout their commuter trips, which suggests cyclists have high situational awareness. However, in general, cyclists were less likely to look to the left. Australia has left lane direction travel, and the reduced checking to the left – the direction which should give way to the cyclist – has also been observed in driving studies where drivers are less likely to look in the direction of the 'lesser threat'(Summala et al., 1996).

Drivers were deemed at fault in the majority of events. In a small number of events, the cyclist did not react before the event which suggests they did not have time to react or did not see the vehicle. These findings suggest that events are more likely to be attributed to a lack of awareness by drivers rather than cyclist inattention. This points to a need to improve driver awareness of other road users. However, there may also be a role for educating or training cyclists to ride more defensively around cars and be particularly vigilant of drivers turning left across their path at intersections, particularly vehicles with poor visibility traits such as large vehicles and 4WDs. Educational information aimed at cyclists and large goods vehicle drivers has been developed in the United Kingdom, following cyclist fatalities that have resulted from large vehicle-cyclist collisions (London Cycling Campaign, 2006, Transport for London, 2010).

The majority of events involved drivers' lane change behaviour (sideswipe/left turn-related). Drivers' lane change behaviour appeared to be motivated by a gap in the adjacent vehicle lane. At times, this resulted in a sudden lane change and often drivers did not indicate (signal), despite the Australian Road Rule that all drivers must indicate for at least 5 seconds prior to turning left or right (Australian Transport Council, 1999). Drivers did not appear to be aware of the cyclist travelling alongside or behind them. While this behaviour did not appear to impact surrounding vehicular traffic, sudden vehicle lane change had a dramatic impact on the cyclist. Successful collision avoidance was reliant on the cyclist's bike handling skills and reaction time.

Cyclists' capacity to affect a response manoeuvre is likely to be influenced by their travel speed. Participants were not fitted with a speedometer or global positioning system (GPS), so travel speed could not be validated. However, cyclists frequently checked their trip computer when riding and the digital readout was occasionally recorded on the video and showed speeds in excess of 40km/h. It is likely that such speeds contribute to cyclists' ability to successfully manoeuvre around a vehicle that makes a sudden change in course. Further research is needed to determine the importance of cyclist travel speeds and available time for collision avoidance manoeuvres, particularly among male cyclists whose observed speeds were higher than for female cyclists.

Given the high proportion of events that were sideswipe/left turn events, adequate overtaking distances are required to ensure that cyclists are afforded a safe clearance space on the roads (Walker, 2007). The need for a one metre clearance zone when overtaking cyclists is promoted by the road authority (VicRoads, 2008b) and included in the learner drivers' handbook (VicRoads, 2007) An education campaign with the message that *a metre matters* has brought attention to the need for greater clearance (Amy Gillett Foundation, 2009). However, observed drivers did not provide sufficient clearance when overtaking cyclists. It is likely that there is also a role for enforcement to shift driver behaviour when overtaking cyclists.

Moreover, it would be ideal if drivers were aware of cyclists and looked for them at all times. However, a practical recommendation with immediate benefits for cyclists would be to increase driver awareness of their requirement to indicate for at least 5 seconds before changing course. This would give cyclists around them time to adjust their line of travel. This could be emphasised in new driver training programs, accompanied by an education campaign and penalties enforced in serious collisions when driver failure to indicate was found to be a contributing factor.

Cyclists also need to take responsibility for their safety, by riding safely and legally and maximising their conspicuity. Conspicuity relates to the visibility of the cyclist by wearing light, reflective clothing and use of front and rear bike lights of sufficient luminance. Also, cyclists need to ensure their position on the road maximises their conspicuity and avoid riding in drivers' blind spots.

Lastly, it is important to consider the role of the road infrastructure and cycling facilities in cyclist safety. A bicycle lane was present in less than half of the observed events and across all event severities. The cycling lanes observed were disjointed and often ended abruptly, frequently where the road narrowed, without a viable option for the cyclist who then either continued in the lane along the kerbside, directly competing with vehicular traffic for space, or rode (illegally) on the footpath. Greater consistency in cycling facility design is needed. A review of existing cycling facilities is also required to improve continuity and provide intuitive end-point options to ensure the road space afforded to cyclists is identifiable. A comprehensive education campaign to ensure cycling facilities are understood by all road users is needed.

Strengths and limitations

The strength of this study was the provision of extensive data on the details of cyclist-driver events. As near-collisions and incidents are not officially reported, the data generated in this study has not been available via any other data source. Due to the positioning of the video camera, this study has provided important insights into the interactions between cyclists and drivers on the road.

The main limitation was a bias caused by the video camera technology. It was identified in the pilot study that the video camera had poor low light sensitivity. Footage recorded pre-dawn or post-dusk was primarily black and no details of the cyclists' trip could be identified (Johnson et al., 2010). Therefore, participants were encouraged to not record their trip during this time. Cyclists did ride during low light times but did not record these trips and therefore there was an overrepresentation of riding during daylight hours in the recorded footage. This limitation is likely to be addressed by advanced in compact video technology.

CONCLUSION

This study has generated a valuable new, in-depth dataset for naturalistic cycling. This practical method provided the cyclists' perspective and allowed analysis of factors mostly highly associated with events and importantly, generated detailed data on the pre-event behaviours of the cyclists and the drivers. Future research using this methodology may include different types of cyclists to determine if the contributing factors identified among commuter traffic are similar in other cyclist types.

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